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Method for Analyzing Trade-offs in Biomass Management in Smallholder Farming Systems Based on Mass Balance

A Case Study in Tajikistan's Foothills

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In smallholder farming systems, especially in mountainous areas, households face trade-offs between meeting short-term human needs and ensuring long-term soil productivity. Improved biomass management can help break the downward spiral of overexploitation of natural resources, land degradation, and productivity decline, and support more sustainable use of marginal land. Mixed crop/livestock systems are often carefully balanced to minimize risks. Thus, when planning interventions, profound systems knowledge is crucial. However, the data required for system characterization are often scarce, and original field studies are thus necessary. The aim of this research, a case study in Tajikistan, was to improve systems understanding of the biomass cycle in crop/livestock systems in order to quantify the obstacles to the spread of sustainable land management technologies to farming households. It aimed to establish a database and methods of rapid data collection to quantify the stocks and flows of biomass, with a focus on mass balances, and to evaluate smallholders' biomass management options and trade-offs. Data collection included household interviews, secondary literature, and reference data sets from global sources. Trade-off analysis focused on household-level self-supply of food, fodder, and fuel by farmers with different sizes of smallholdings, and their potential for on-farm recycling of organic matter. Results indicate that food self-supply by small and medium smallholders is insufficient and fodder sources are scarce. Fodder scarcity means that application of crop byproducts to soils is unlikely. Animal dung is largely used as fuel. Firewood needs exceed on-farm wood production, leading to deforestation. The approach presented facilitates an understanding of current and potential agricultural land interventions in the crop/livestock farming systems prevailing in mountainous areas.

Keywords: *Biomass management; mass balance; trade-off; smallholder; crop/livestock system; self-sufficiency; soil conservation; sustainable land management; Tajikistan.*

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Introduction

Smallholders and subsistence farmers often dominate the agricultural landscape in developing countries, frequently using mixed crop/livestock systems (IAASTD 2009). In mountain regions in developing and transitional countries, an estimated 40% of the population (270 million people) is vulnerable to food insecurity, and half of this number suffer from chronic hunger. Moreover, environmental degradation is widespread in many of these regions, and, with some notable exceptions, environmental protection has failed to keep pace with progress in the surrounding lowlands (Maselli 2012; Ariza et al 2013).

Although agriculture provides critical household needs such as food, fodder, and fuel (MA 2005), overexploitation of land resources threatens the natural capital and functioning of ecosystems (IAASTD 2009). This presents an existential dilemma for land use, which requires management of trade-offs between meeting immediate human needs and ensuring the long-term continuation of ecosystem services (Foley et al 2005).

Mountainous regions are especially vulnerable to climate changes, and thus require optimal land management (Grêt-Regamey et al 2012; Ariza et al 2013). Better management of on-farm biomass is a part of sustainable land management (Liniger et al 2011) and conservation agriculture (Valbuena et al 2012). However, there is considerable controversy about the promotion of conservation agriculture in smallholder farming systems (Giller et al 2009), because human and livestock needs often compete with soil-conservation needs for the same

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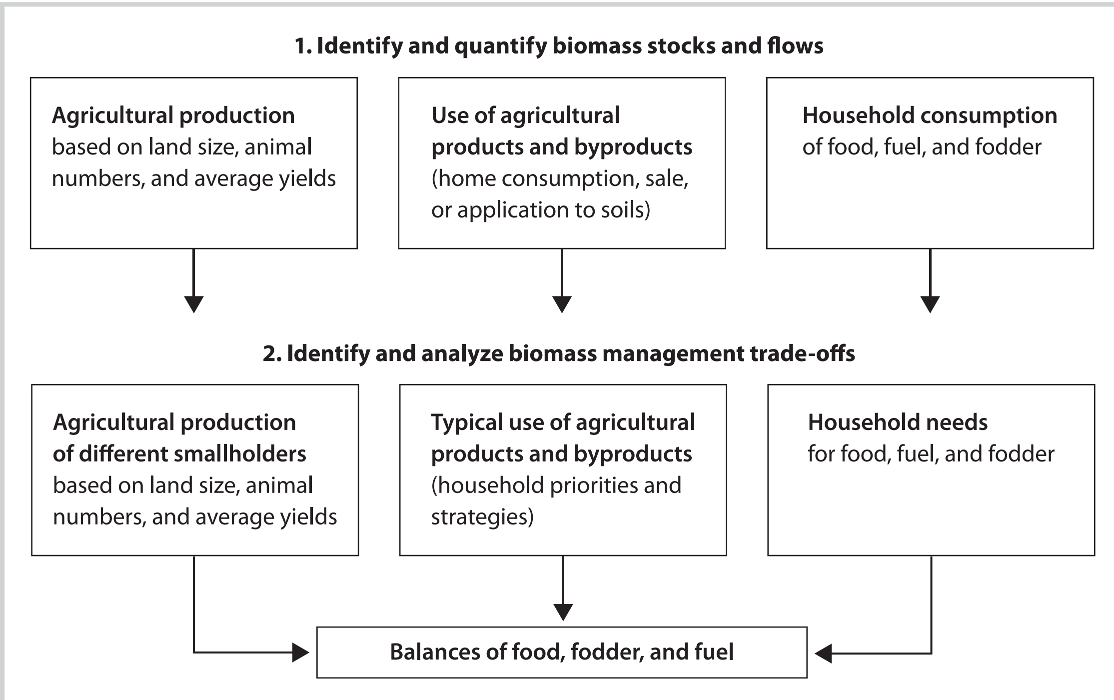
FIGURE 1 Study procedure: quantifying biomass stocks and flows and evaluating self-supply and potential application of organic matter to soils among subsistence smallholders.



organic matter in those systems (Bot and Benites 2005). It is crucial to understand these interrelations in order to support effective soil management. Trading long-term soil conservation goals for short-term production aims can result in severe depletion of soil nutrients and organic matter, especially for smallholders, many of whom have scarce access to organic and inorganic fertilizer at local markets (FAO 2005; IAASTD 2009). As Lal (2009) pointed out, it is essential to enhance the pool of soil organic matter in order to restore degraded soils, increase food security, and improve the environment. The application of biomass and decomposing biomass products to soil organic matter is a precondition for achieving this goal.

Systems knowledge is required as a basis for managing the trade-offs between meeting human needs and conserving natural resources, desirable but often competing objectives (Foley et al 2005). The methods used to assess trade-offs can be differentiated into participatory methods, empirical analysis, system optimization models, and simulation models; a combination of these is often required (Klapwijk et al 2014).

Because statistical data are typically scarce and often unreliable in developing countries, field-study approaches are needed that enable a rapid characterization of smallholder systems. Tittonell et al (2005) elaborated a general approach to rapid system characterization, aiming at developing farm typologies and providing information on methods of data collection. However, a more specific characterization is needed for the biomass management trade-off between short-term human needs and long-term soil conservation.

The aim of this case study, which took place in Tajikistan, was to improve systems understanding of the biomass cycle in crop/livestock systems in order to quantify the obstacles to the spread of sustainable land-management technologies to farming households. It established a database and methods of rapid data collection in order to quantify the stocks and flows of biomass and to evaluate smallholders' biomass management options and trade-offs. It did this by means of the mass-balance method, which—based on the principle that, within a closed system, total mass remains constant—identifies all mass inputs and outputs to a system and recognizes any change in total mass as the difference between total inputs and total outputs.

Approach to assessing biomass management by smallholders

The integrated approach to characterizing and analyzing biomass management by smallholders was developed for this study and comprises 2 major steps (Figure 1):

1. Identifying and quantifying the stocks and flows of biomass at the household level, including by gathering data on agricultural production, priorities for the use of agricultural products and byproducts, and household consumption;

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TABLE 1 Contents of the database on smallholders' biomass management developed during this study.[a)]

	Unit of measure	Data source		
		Interviews	Secondary data	Reference data
Agricultural production				
Crops and grassland in the study area, crop management practices (eg irrigation and fertilization), and the use of their products and byproducts	n/a (list only)	QI		
Crop and grassland productivity	kg ha^{-1} y^{-1}	QI		FAOSTAT
Dung from livestock kept in the study area	kg y^{-1}	QI		Scientific literature
Seasonal calendar for livestock feeding (daily pasture, seasonal pasture, stall feeding)	Week or month	QI SI		
Smallholders' production structure				
Landholding size, animal numbers, number of household members, income activities	Various	QI	Project reports	
Household consumption				
Food, fuel, and cash crops	n/a (list only)	QI		Project reports
Human consumption per household and per capita	kg y^{-1}	QI	Project reports	FAOSTAT; project reports
Fodder sources for livestock	n/a (list only)	QI		
Typical fodder intake for each animal type	kg y^{-1}	QI	Scientific literature	

[a)]Volume amounts are measures of dry matter. n/a, not applicable; QI, interviews based on the biomass questionnaire; SI, semistructured interviews with local pasture management experts.

2. Identifying and analyzing biomass management trade-offs, using mass balances, revealing and evaluating obstacles to self-supply, and deducing potentials for the application of biomass to soils.

To define a smallholder biomass management system, it is necessary to identify and quantify current biomass management practices. System borders, stocks, and internal and external flows were determined for this purpose through informal talks and subsequent questionnaire-based interviews addressing the questions: What is produced? And what is it used for? The result of this is called system definition.

To efficiently identify and quantify biomass stocks and flows, field data, secondary data, and reference data were combined (Table 1). Field data were collected using a biomass questionnaire (*Supplemental Material*, Appendix S1: http://dx.doi.org/10.1659/MRD-JOURNAL-D-14-00114.S1). When such a questionnaire is used in a new study area, it must first be tested—through review of existing literature, informal talks with farmers, and field observations—and adapted, along with the basic system definition, where necessary. Questionnaire-based interviews were then conducted to systematically quantify the biomass management practices of selected smallholders' households in the study area. In order to fill data gaps, secondary data were used; reference data were used to assess the reliability of the field and secondary data.

To optimize the benefits gained by smallholders from agricultural outputs, conflicts between household and livestock needs and on-farm soil conservation must first be identified. To this end, smallholders were asked about their use of agricultural products and byproducts and the authors determined their priorities by comparing how often different uses were mentioned.

Next, the interviewed smallholders and their households were categorized on the basis of their production structure—an essential step in agricultural research and development, as it helps to reveal the vulnerability and resilience of smallholder systems (Grandin 1988; Pfister 2003). The production structure

FIGURE 2 Location of the 2 study areas. (Map by Bettina Wolfgramm)

was defined using the area of land managed and number of animals kept—common criteria in similar studies (Shepherd and Soule 1998; Pfister 2003; Shigaeva et al 2007). We divided the smallholders participating in the study into 3 categories: small, medium, and large. For each smallholder category, parameters were derived from the interview data. Stocks and flows of biomass were calculated on the basis of these parameters.

Information about smallholder categories, their agricultural production and priorities for its use, and their household consumption allowed self-supply obstacles to be identified and the agroecological potential of biomass recycling to be evaluated from a mass-balances perspective. As in previous studies, household self-sufficiency was calculated as the annual on-farm production of a certain commodity divided by the annual need for the same commodity, measured in dry matter (Shepherd and Soule 1998; Pfister 2003). For these highly subsistence-oriented farming systems, it was assumed that each household endeavored to meet its own needs for food, fodder, and fuel before selling agricultural products externally or applying crop byproducts or animal dung to soils.

Case study in Tajikistan's foothills

Study region

Tajikistan is mountainous and highly agrarian. Resource-poor farming households are widespread and have a high level of self-sufficiency in food, fodder, and fuel (Mandler 2010). Agricultural land is often degraded and declining in fertility (UNEP 2006). Seasonal migration is widespread, and remittances play a key role in the strategies adopted by smallholders' households to cope with deficits in food self-supply (ILO 2010).

Figure 2 shows the 2 districts in western Tajikistan's foothills selected for this study, Faizabad (68.5°N, 69.3°E) and Muminabad (38.1°N, 70.0°E). Both are characterized by hilly terrain (Figure 3), predominantly loessial soils, and an annual precipitation between 700 and 900 mm, with the highest precipitation occurring from November to April. Land degradation, especially soil erosion, soil fertility decline, and deforestation, is widespread (Wolfgramm et al 2007; Strahm 2011).

Smallholder crop/livestock systems are widespread in both study areas. For this study, a household was defined as a group of people who normally live and eat together on a daily basis. In Tajikistan, this can include several generations. Wheat is the major food crop and is commonly grown in rain-fed areas in Tajikistan. Potatoes, onions, and other horticultural crops are cultivated on irrigated plots. One cropping season is the norm; a second crop is possible only on irrigated plots. Most households keep cows, sheep, goats, or chickens, and some keep donkeys or horses. Cows, sheep, and goats graze on common pastures in summer and are kept in barns in winter. Many households use large amounts of animal dung and wood for cooking, baking, and heating (eg UNEP 2006; Kirchhoff and Fabian 2010; Mislimsheova et al 2014).

Data and methods

Little information exists about biomass stocks and flows in the study areas, thus making field study necessary. Interviews with farmers were conducted between June and September 2011.

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FIGURE 3 A Muminabad landscape typical of the study region with food plains and moderate-to-steep slopes. (Photo by Sebastian Ruppen)

In a first step, informal talks with farmers and field observations were carried out to gain the information needed to develop the interview questionnaire; this can be found in the *Supplemental Material*, Appendix S1 (http://dx.doi.org/10.1659/MRD-JOURNAL-D-14-00114.S1). For use in new regions, the questionnaire needs to be adapted on the basis of the relevant literature, field observations, and informal talks. In a second step, questionnaire-based interviews were conducted with 21 smallholders, 10 in Muminabad and 11 in Faizabad. The study also drew on a complementary data set on household energy consumption, based on interviews commissioned for this study and carried out in 35 households from 2 villages in the Faizabad study area in February 2011.

Smallholders were chosen randomly for the informal talks. For the questionnaire-based interviews, smallholders representing the different types of mixed crop/livestock farming in the study region were selected in cooperation with local key informants. They differed in the amount of land cultivated and number of animals kept and in their land use (irrigated or rainfed cropland) and sustainable land management strategies (agroforestry, perennial forage crops, mulching, and energy efficiency). Two semistructured interviews were additionally carried out with local pasture management experts to obtain more detailed information on pasture management and the seasonal dynamics of fodder supply.

To quantify biomass stocks and flows, interview data about levels of production and consumption were used and validated with existing reference data, including the FAO's statistical database (FAOSTAT) available online and energy survey data for different areas in rural Tajikistan (Löwen and Wegner 2009; Stevenson and Lerman 2011). Data from FAO's statistical database provided a reference for quantities of agricultural production and food consumption for a wide range of crops. However, these figures refer to national averages derived from information provided by the governments in question, and data can differ considerably between study sites in the same country, depending on local environmental and agricultural conditions. Residue-to-yield ratios taken from the literature were used to estimate quantities of crop byproducts. Animal consumption and dung production estimates were based on typical amounts of fodder intake and digestibility rates for the animals in question, using values from the literature (Schiere 2001).

Results and discussion

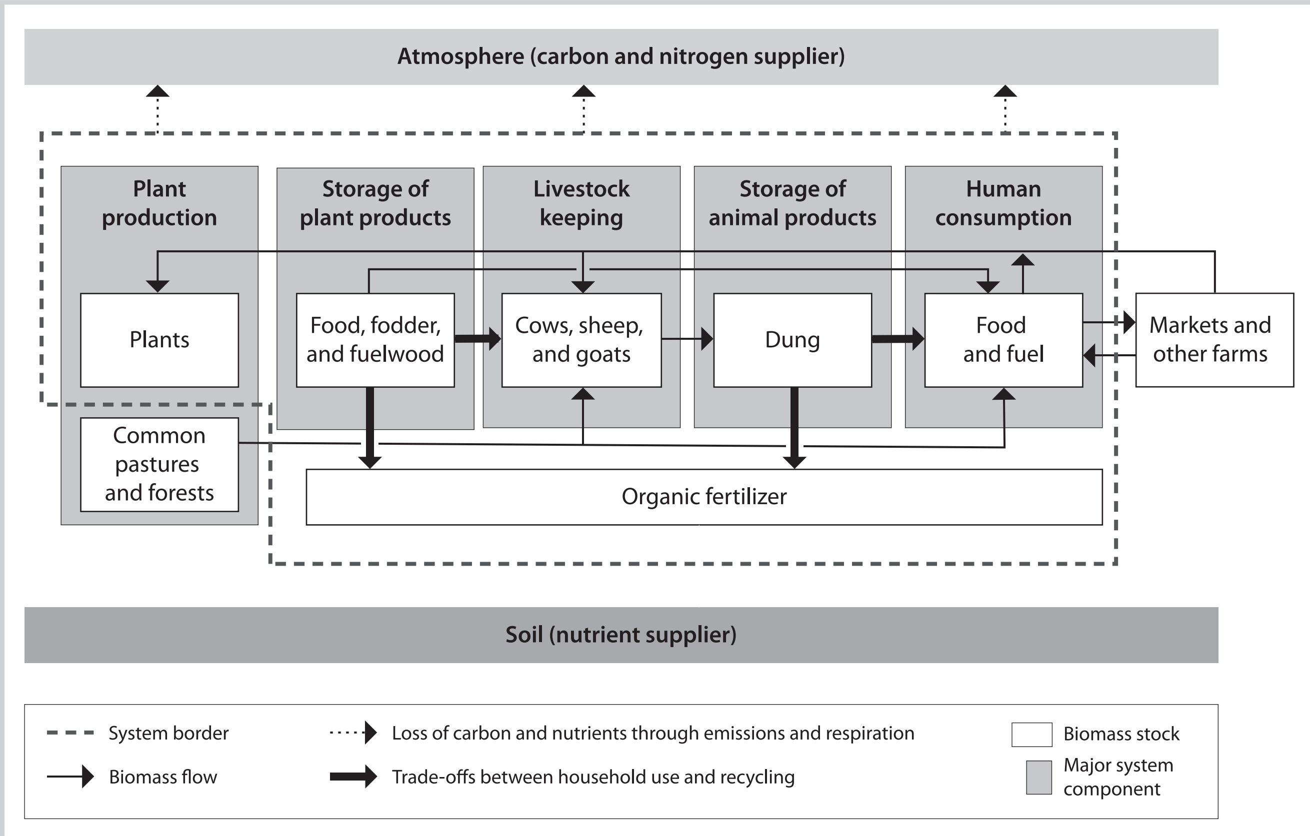
System definition

A smallholder biomass-management system typical of the study area is shown in Figure 4. This definition focuses on mixed crop/livestock farming systems and agricultural products and byproducts used directly by the households. It is applicable to all types of farms. Five components are differentiated: plant production, storage of harvested plant and animal products, and animal and human consumption. Organic fertilizer use is also incorporated, making it possible to determine integrated flows between the system components and the soil.

In the system definition, pastures were considered an external source of fodder, as these areas are managed jointly at the village level and are outside the control of individual smallholders. Consumption of meat and dairy products is low in the study areas and was consequently excluded from the system definition. Human food consumption was considered as a loss of biomass, because the use of human feces as fertilizer is not practiced in the study areas; it was therefore excluded from the mass-balance analysis. The burning of firewood and animal dung was also considered a loss of biomass.

The biomass management trade-offs between meeting household needs and improving soils considered in this study were (1) use of plant products as livestock feed or fertilizer and (2) use of animal dung as fuel or fertilizer. In the study area, households typically sell any surplus food, and compensate for insufficient supplies of food, fodder, and fuel by purchasing them at local markets or by borrowing from others (WFP 2010). However, according to interviewees, organic fertilizer is almost unavailable at local markets. The dimensions of the biomass stocks and flows can change depending on smallholders' amount of land and number of animals, as discussed in the following section.

FIGURE 4 A typical smallholder biomass-management system in western Tajikistan's hill zone.



Smallholder categories

Three smallholder categories were differentiated based on land size and animal numbers: small, medium, and large. The Famine Early Warning Systems Network made a comparable differentiation (FEWS NET 2011) and reports specifically on 2 classes: poor households (cultivating 0.2–0.5 ha) and better-off households (cultivating 5–10 ha). We specified an intermediate category in order to compare a broader range of resource availabilities. Table 2 lists smallholder characteristics for each interviewed smallholder, including household size, land size, number of animals, and other income sources (remittances, regular employment, and daily wage labor) besides sale of agricultural products.

Data from a previous study in 2 villages in Faizabad with a sampling of 149 households (Eggenberger 2011) indicated the distribution of small, medium, and large smallholders. According to the smallholder categories used in our study, about 65% of the respondents' farms in that study would be classified as small, about 30% as medium, and about 5% as large. Table 3 shows parameters for each smallholder category defined for calculating the mass balances.

Agricultural production

In the study areas, plant production for human and animal consumption takes place on farms and pastures. One cropping season is the norm. The yield of wheat, the major food crop, is 1.3–1.4 t/ha. This is less than the yield recorded by the FAO's statistical database, namely an average of 1.9 t/ha during 2000–2009 (FAOSTAT). The difference can be explained by the low fertilizer input levels practiced by our interviewees and the mountainous conditions in the study areas. Because the cultivated areas are small and the smallholders are exemplary, some yield figures may be unreliable. Nevertheless, we consider most of the production data reported by the smallholders to be plausible.

Fruit trees are generally combined with food crops, fodder crops, or grassland. Apples and cherries are the most common fruits grown in the study areas, according to interview statements (and confirmed in Rowe 2010). The average tree density is about 250 trees/ha. Fruit trees are annually pruned in late winter. The amount of wood pruned per mature tree per year is about 6 kg, according to the interviewees. These values appear plausible compared with fruit tree studies from other regions (eg Velázquez-Martí et al 2011a, 2011b). More detailed estimates would require more data from the study

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TABLE 2 Characteristics of smallholders who participated in the questionnaire-based interviews (each column represents 1 smallholder).

Household size											
Total members	7	7	8	16	23	24	22	14	12	12	10
Children	0	0	0	10	14	10	9	0	6	6	2
Agricultural production[a)]											
Total land managed (ha)	**27**	**14**	**10**	**7**	**8.5**	**5.5**	**5.4**	4.5	4.0	3.6	2.3
Irrigated land	7.1	3.0	0.0	3.0	1.5	2.4	0.4	2.0	0.5	0.0	0.0
Total animals	**110**	7	**14**	**16**	**12**	**12**	8	4	**23**	**11**	9
Number of cows	15	4	4	4	2	4	8	4	3	8	4
Number of sheep/goats	95	3	10	12	10	8	0	0	20	3	5
Other income sources											
Remittances					x	x	x		x		
Regular employment				x					x		x
Daily wage labor											

TABLE 2 Extended.

Household size										
Total members	9	8	7	7	8	6	9	5	5	5
Children	1	3	3	2	0	2	0	0	3	3
Agricultural production[a)]										
Total land managed (ha)	2.0	1.5	1.2	1.0	0.97	0.86	0.70	0.65	0.12	0.03
Irrigated land	0.0	0.5	1.2	0.2	0.55	0.01	0.20	0.15	0.03	0.03
Total animals	0	6	6	4	1	3	8	1	0	0
Number of cows	0	6	2	4	1	3	1	0	0	0
Number of sheep/goats	0	0	4	0	0	0	7	1	0	0
Other income sources										
Remittances				x						x
Regular employment		x	x			x	x		x	
Daily wage labor								x		

[a)]For agricultural production, **bold** = >5 ha of land or >10 animals; underline = 1–5 ha of land or 3–10 animals; no font style = <1 ha of land or <3 animals.

region on tree species, age, and corresponding yields over several years.

Cows, sheep, and goats are the crucial animals for the households because of their milk, meat, and dung production and their value as assets. This study found that these animals strongly influence the biomass flows in terms of fodder consumption and dung production. (Horses, donkeys, and chickens were excluded from the analysis, because the number of horses and donkeys is generally low and the influence of chickens on biomass

TABLE 3 Parameters of small, medium, and large smallholders defined for the study areas, based on land size and number of animals.

	Small	Medium	Large
Total land (ha)	**0.60**	**2.75**	**7.00**
Wheat	0.20	0.50	2.00
Chickpeas and/or other cereals	—	0.25	1.00
Horticultural crops	0.1	0.15	1.65
Perennial forage crops	—	0.35	0.35
Orchard/vineyard with haymaking	—	0.75	1.00
Haymaking without trees/vines	0.30	0.75	1.00
Total animals	**1**	**9**	**14**
Cows	1	4	4
Sheep/goats	—	5	10

flows is considered marginal.) Livestock weight and excretion can differ considerably depending on factors such as their genetic potential, natural and structural conditions, and production intensity (Gerber et al 2005). Animal dung production was estimated on the basis of digestibility rates derived from livestock weights. Schiere (2001) used an average digestibility rate of 55% of daily dry matter intake for animals weighing 250 kg and 60% of daily dry matter intake for animals weighing 25 kg. As detailed information on livestock weights was not available for Tajikistan, we assumed that in the study region a cow weighs roughly 250 kg and a sheep or a goat roughly 25 kg.

Household consumption

Table 4 shows estimated annual household food, fodder, and fuel consumption in the study region and reference datasets from other regions for validation purposes. Our estimates appear consistent with the per capita figures for food consumption listed by FAO's statistical database (FAOSTAT 2011) and energy survey data for different areas in rural Tajikistan (Löwen and Wegner 2009; Stevenson and Lerman 2011). The distribution of values shows large differences in food and fuel consumption. Differences in food consumption are mainly due to the number of household members (with food amounts and household member correlating highly), whereas an important factor affecting differences in fuel consumption is the accessibility of alternative fuel sources such as coal, gas, and electricity (Mislimshoeva et al 2014). We focused our study on household wheat consumption, as interview results showed that wheat is the major food crop.

Our results on fuel consumption reveal that wood and dung are essential energy sources for cooking, baking, and heating. The heating period lasts from November to March or April. Of 21 households participating in the study, 20 reported using wood for baking, cooking, and heating; all reported using animal dung for cooking and baking; and 14 reported using animal dung for heating.

TABLE 4 Estimated average annual food and energy consumption in the study region (kg y^{-1}).

	Consumption per household					Consumption per capita	
	Study region (Faizabad/Muminabad)			Rasht	East Khatlon	Study region	Tajikistan
	First quartile	Median	Third quartile	Mean	Mean	Mean	Mean
Wheat	1000[a)]	1500[a)]	2400[a)]			180[a)]	160[d)]
Fuelwood	1696[b)]	3488[b)]	5825[b)]	3900[c)]	5100[c)]		
Dung	864[b)]	2430[b)]	4527[b)]	2400[c)]	8800[c)]		

[a)]Data from interviews using the biomass questionnaire (*Supplemental Material*, Appendix S1: http://dx.doi.org/10.1659/MRD-JOURNALD-14-00114.S1).
[b)]Data from complementary dataset on household energy consumption, based on interviews commissioned for this study comprising 35 households in Faizabad.
[c)]Data from Löwen and Wegner (2009).
[d)]FAOSTAT (data from 2000–2009).

Fruit trees and cultivated vines are the main sources of wood. Animal dung is collected in the barns. This agrees with Robinson et al (2008), who stated that households in Tajikistan tend to use only animal dung from their barns. However, 6 households also reported collecting dung from animal resting areas during daily pasturing in summer. For this study, however, we assumed that only animal dung accumulated in the barn is used as fuel.

The results on fodder consumption show that cows, sheep, and goats graze on common pastures at higher elevations during the summer. From the end of July to November or December, daily grazing on the stubble of harvested plots is common. From November/December to March/April, livestock are stall fed; by the end of this time, household fodder stocks are usually depleted. Hay, perennial forage crops, and wheat straw are essential sources of fodder. Most smallholders feed kitchen-garden byproducts and kitchen wastes to their animals. Only 6 smallholders (3 in each study area) out of 21 reported returning some crop byproducts to the soil.

This study assumed that the cows, sheep, and goats have a constant dry matter intake throughout the year. However, fodder sources can in fact change throughout the year. The daily dry matter intake of a 250-kg cow is around 6.3 kg or 2.5% of its own weight. This corresponds approximately to the rough estimates mentioned by farmers in the interviews. A 25-kilogram goat or sheep has a daily dry-matter fodder intake of around 3.2% of its own weight.

Our data on consumption of organic fertilizer show that besides being used as fuel, animal dung is also used as fertilizer. Five out of 21 smallholders reported applying dung from their own animals to irrigated plots by adding dung into the water during flood irrigation. Additionally, 2 smallholders reported using dung from large animal farms nearby, and another smallholder reported collecting dung from animals' resting places during daily pasturing.

Trade-offs in biomass management

We assumed that each household endeavors to meet its own food, fodder, and fuel needs before using biomass (crop byproducts or animal dung) to improve the soil. Household self-sufficiency levels in food, fodder, and fuel can therefore be used as an indicator of the feasibility of biomass management options. When a household is self-sufficient in fodder and animal dung, it has the potential to apply biomass to soils as fertilizer. Low household self-sufficiency of fuelwood often results in pressure on common forests, in the form of illegal tree and shrub clearing (UNEP 2006). Moreover, low household food self-sufficiency has a crucial influence on smallholders' production structure and indicates food intake quantities for rural households in Tajikistan's foothills (Table 5).

Crop byproducts and dung are important potential sources of soil nutrients. However, the supply of fodder to small farmers is insufficient to meet the animal demand when only hay, perennial forage crops, and wheat straw are used as fodder; in these cases, crop byproducts must be used as fodder throughout the winter. As a result, crop byproducts are seldom available for application to soils on such farms. The situation is similar regarding the application of dung to soils. On small farms, there is little potential to use animal dung as fertilizer, because most or all of it must be used as an energy source. These findings indicate that, especially on small farms, immediate household needs compete with soil conservation strategies such as composting, mulching, and manuring, and can prevent these strategies from being applied. This is a likely explanation for the depletion of organic matter from soils in rural Tajikistan reported in previous studies (Wolfgramm 2007; Robinson et al 2008; Löwen and Wegner 2009). The data collected in the interviews showed that large farms are more likely to apply animal dung to soils (but only on irrigated plots during flood irrigation) and to leave crop byproducts on the field. However, in all categories of smallholder farms, some households had high levels of self-sufficiency in dung (Table 5, dung self-sufficiency, first quartile), and they have the option of applying dung as organic fertilizer to their land.

Fruit trees cultivated in fields are an important source of firewood. However, none of the farms met its own need for firewood with the wood pruned from fruit trees. Under these conditions, deforestation appears likely to continue on common forest and pasture land, thus increasing land degradation as well as the likelihood of natural disasters such as mudslides and landslides (Olimova and Olimov 2012).

Wheat is the most important food crop in the study areas. However, small and medium farms do not produce enough wheat to meet their own needs. This gap in self-sufficiency indicates that meeting food demands has a major influence on a farm's decisions on the adoption of sustainable land management practices. It also indicates that there is a risk of temporary food insecurity in subsistence-oriented households. These results agree with the findings of the Integrated Food Security Phase Classification in Tajikistan (WFP 2008). Our results showing a clear food gap are also in line with the fact that many households have at least 1 member working as a migrant abroad, whose remittances are mainly used for buying food. This study included food self-sufficiency as a crucial effect of the production structure of the farms, but did not aim to assess food security.

Conclusion

A lack of self-sufficiency was evident in the study areas. This leads to a threat of soil depletion, further threatening the resource base upon which people's livelihoods depend. These results are in agreement with

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TABLE 5 Food, fodder, and energy self-sufficiency of small, medium, and large smallholders assuming average production and 3 ranges of household consumption. The values represent annual household production divided by annual household demand, measured in kg of dry mass.

Consumption ranges	Wheat			Fodder[a), b)]
	First quartile	Median	Third quartile	Mean
Small	0.27	0.18	0.11	0.78
Medium	0.68	0.45	0.28	1.00
Large	2.70	1.80	1.13	1.56

TABLE 5 Extended.

Consumption ranges	Fuelwood			Dung[b)]		
	First quartile	Median	Third quartile	First quartile	Median	Third quartile
Small	0.00	0.00	0.00	0.80	0.29	0.15
Medium	0.40	0.19	0.12	3.67	1.30	0.70
Large	0.53	0.26	0.15	4.12	1.47	0.79

[a)]Fodder consists of hay, wheat straw, alfalfa, and esparzet. Straw residue to yield ratio = 1.3 (Nordblom et al 1997).
[b)]Daily dry matter intake/digestibility: cow 6.3 kg/0.55; sheep, goats 0.8 kg/0.60 (Schiere 2001).

the conclusions of other studies that current household biomass management is a likely cause of severe soil degradation.

Although sustainable land management practices are already being applied in the study areas, and are available online in the database provided by World Overview of Conservation Approaches and Technologies (WOCAT 2011), their application remains infrequent. To support sustainable land management practices, such as establishing orchards, composting, mulching, and manuring, their potential effect on households in the different smallholder categories must be assessed—including their effect on household supply, availability of biomass for application to soils, and thus soil productivity and conservation.

The method of analyzing biomass management elaborated in this article can contribute significantly to such an assessment. This approach makes it possible to quickly characterize biomass management, on the scale of a smallholder farm household, and identify options for both self-supply and biomass recycling. It facilitates an understanding of current and potential agricultural land interventions in the crop/livestock farming systems prevailing in mountainous areas. This systems understanding is essential for decision-making and land-use planning. The approach also allows data that are generally distributed among different types of publications (eg reports, statistical databases, and scientific publications) to be synthesized.

This approach is also applicable to other crop/livestock systems. It allows an improved understanding of the local agroecological system. For a further step, a spatial differentiation of field plots (eg irrigated or rain-fed) and external factors, such as fertilizers or alternative fuels, affecting biomass stocks and flows would have to be considered. Mass balances would have to be calculated for organic carbon and uncertainty levels determined. These factors depend on other off-farm income sources (eg labor migration) and market access (for both sale and purchase), as well as other household socioeconomic strategies.

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Supplemental material

APPENDIX S1 Biomass questionnaire.

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